24th ABCM International Congress of Mechanical Engineering
December 3-8, 2017, Curitiba, PR, Brazil

COBEM-2017-1239
ANALYSIS AND MATHEMATICAL MODELING OF THE ELETRIC THRUST SYSTEM OF A QUADCOPTER TO OBTAIN FLIGHT PERFORMANCE CRITERIA

Flaianny Bastos Pacheco
Rhillame Valéria Lago da Silva
flaiannypacheco@gmail.com;
rhillame-1994@hotmail.com.

Denner Guilhon
Universidade Estadual do Maranhão, Department of Mechanical Engineering and Production Engineering, São Luis, Brazil
dennerguilhon@cct.uema.br.

Abstract. *To evaluate the efficiency of a quadcopter propulsion system, tests were performed on an experimental bench, equivalent to 1/4 of the aircraft frame, using a AX-2810Q brushless motor, 10x4.5" and 8x4.5" propellers, along with 4A ESCs. In order to obtain better results, preliminary studies on mathematical modeling were performed considering the system based on the lever method. The parameters obtained were the thrust and the torque, aiming to evaluate the influence of the propeller diameter over the effectiveness of the aircraft. . The bench was designed using SolidWorks 3D design software. Additionally to the physical tests, simulated tests were performed using the SolidWorks simulation tool to validate the results obtained experimentally. The employment of that tool made possible to visualize the behavior of the assembled structure according to the buoyancy variation. During the tests, vibrations observed in the structure, we were concerned to analyze their amplitude in order to evaluate their interference.*

Keywords: *Quadcopter, Propeller, Thrust, Torque.*

1. INTRODUCTION

The development and use of Unmanned Aerial Vehicles (UAVs) has been driven by technological advance, so that they can be employed for monitoring areas that offer risk to human life, military operations, image capture, surveys of transmission lines, among others applications. UAVs are vehicles controlled autonomously or remotely, usually with electric propulsion (Güçlü, 2012).

They can be classified as fixed wings and rotating wings, used in military operations, border security operations, and civil applications such as image capturing. The vast applicability of this type of aircraft has led to intensive research and development of technology in the area, both to study the employment and to improve performance in the goals they are supposed accomplish (Costa, 2008).

Quadcopters generally are small, possess great maneuverability to land and take off vertically, and are dynamically simpler compared to other UAVs. Thus, they have become popular in reaching inaccessible places. The structure of a quadcopter is composed of four rotors arranged symmetrically with respect to the structure's center of gravity, where two rotors need to rotate clockwise while the other two rotate counterclockwise to cancel the spin effect between them and stabilize in the air. The main characteristics found in quadcopter are symmetry and rigidity of the structure, avoiding unstable flights (Naidoo, 2011). In the center of the structure are placed the controller board, battery, sensors and all other electronic parts that will assist in the vehicle control (Costa,2008).

The study of the constituent parts of a quadcopter is required to guarantee is correct and efficient operation, where the motor-propeller pair is one of the most influential factors on the aircraft's performance (De Four, 2007).

A bench was built in order to analyze, based on the method of the lever, the propeller-motor pair and the influence of the change in propeller diameter over the lift. A workbench was designed and simulated using SolidWorks 3D software and its simulated results were compared to those obtained experimentally.

It is known that not every engineering project is tested from a prototype, because many times it becomes unfeasible to make full-size prototypes of large projects, or even small ones, when you consider the costs. For these reasons, many engineers often model, simulate and analyze the results obtained prior to the construction of the prototypes.

Simulink is a MATLAB block-programming tool used to model, simulate and analyze dynamic systems. Simscape is a Simulink toolbox that features detailed pre-programmed models of electromechanical systems (Guimarães, 2014).

The present work proposes the study of the motor-propeller pair, analyzing values of thrust and torque obtained experimentally and comparing the simulated results, using the software SolidWorks and Simscape.

2. METHODOLOGY

For this work, a prototype test bench with only one degree of freedom was constructed. For data verification and validation, the bench model design was firstly simulated in the SolidWorks, including all the necessary restrictions for the physical assembly of the prototype, as shown in Figure 1.

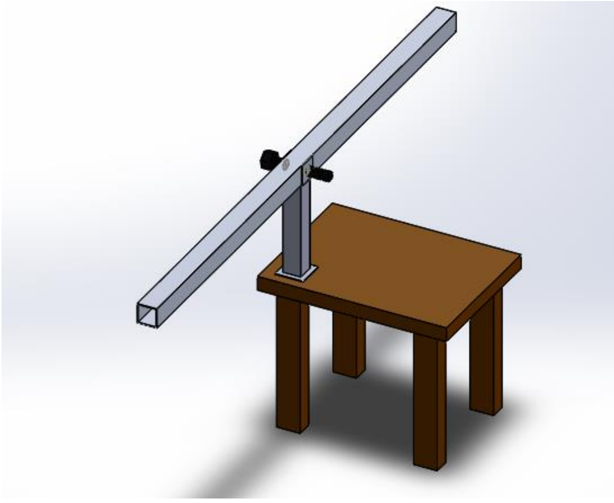

Figure 1. Prototype test bench in SolidWorks

The selected model was built using 6063-T5 aluminum and fixed to a rigid structure capable of withstanding the force exerted by the brushless motor. The structure has a main rod, 60 centimeters long. In it was placed the electronic speed control (Esc), motor, a suitable propeller and a vibration sensor. In order to control the motor speed, an Arduino Uno board programmed to increase the engine power by 2.67% every 3 seconds until 60% of power was reached, while a digital tachometer was used to obtain the propeller rotation. Figure 2 shows the displacement of these components on the bench

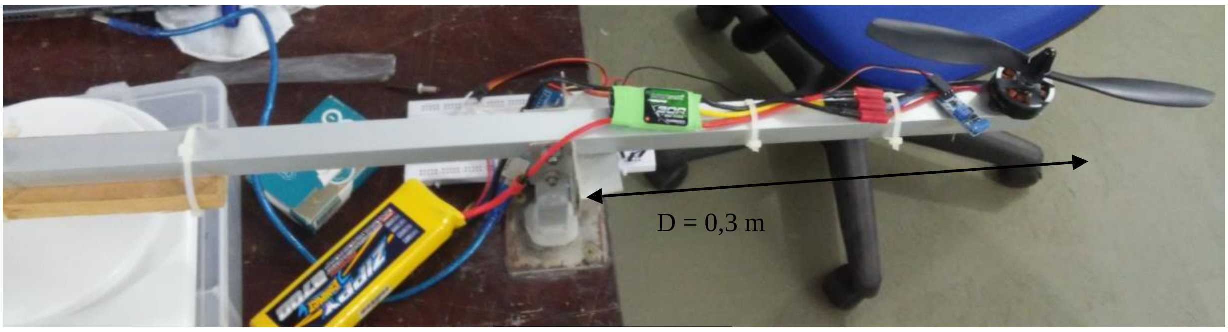

Figure 2. Test bench assembly

Table 1 lists the materials used and their specifications.

Table 1. Materials used

MATERIALS	SPECIFICATIONS
Esc (eletronic speed control)	30 amps
Lipo batery	25C Series
Arduino	Uno
Brushless Motor	AX-2810Q

D = 0,3 m

Propellers	10x4,5" and 8x4,5"
Jumpers	Male-male conector
Digital scale	SF-400
Protoboard	170 pontos

Figure 3 shows the model drawn in SolidWorks. Figure 4 shows the block diagram after the model is exported to Simscape.

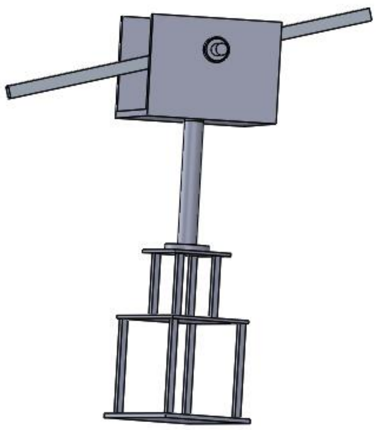

Figure 3. Bench representation in SolidWorks

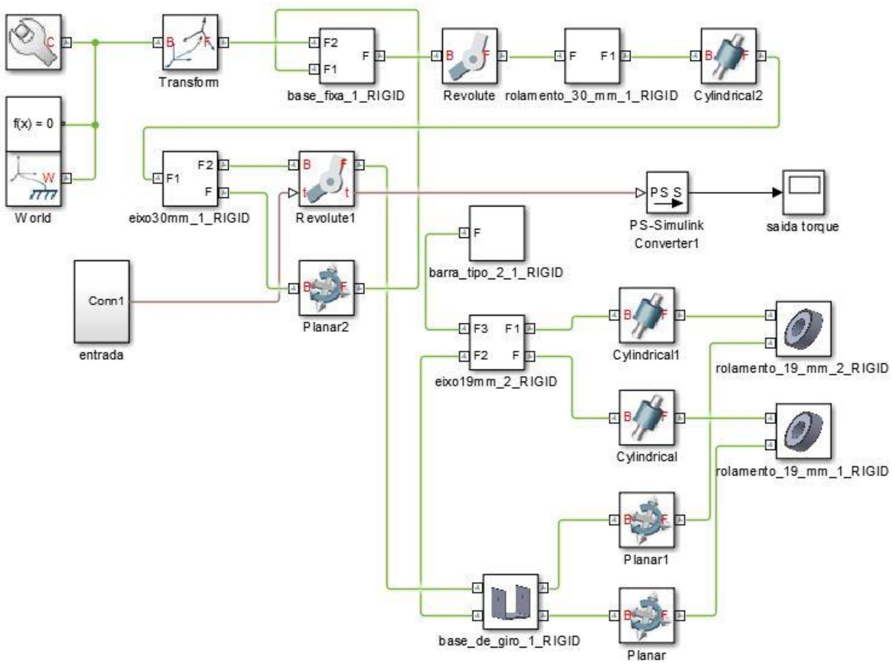

Figure 4. Block diagram of test bench in Simscape

2.1 Experimental Procedure

For calculations, we used the lever method to obtain an adequate control of the quadcopter dynamic behavior (Da Silva).

Based on these concepts, the thrust (Emf) and torque (T) were found using Eq. (1) and Eq. (2), respectively:

$$Emf = m * g \tag{1}$$

$$T = Emf * D \tag{2}$$

The distance (D) is measured from the point of attachment of the rod to the base to the rod's end, as shown in figure 2.

When exporting the assembly from SolidWorks to Simscape, it was divided into blocks, each representing an element and their respective positioning and constraints, as shown in Figure 3. In SolidWorks, the maximum torque obtained experimentally was determined to analyze the vibration of the workbench .

The rotations of 40% to 60% of engine power, with a variation of 5%, were obtained using a digital tachometer, and through interpolation it was possible to estimate the rotations for other values of power variation.

2.2 Results and Discussions

In order to calculate the thrust force (N) and torque (Nm), the vibration amplitude of the bar was calculated using the following variables: motor power, mass in kg obtained on the scale. The amplitude of vibration observed in the bar to which the motor is fixed was obtained through a SW-420 sensor, using the *pulsein* function in the Arduino. All these parameters are important for the analysis of propeller efficiency used.

Tables 2 and 3 show the average results of 3 tests using 8x4.5 "and 10x4.5" propellers, respectively. It was observed that up until values of 34.67% of both propellers have not generated forces and, consequently, there was no measured vibrations. For that reason the following tables start at 37.33%. It was not possible to check the vibration amplitude at 60% power.

Table 2 Test Results - Propeller 8x4.5 ".

Propeller 8x4.5”		
% Motor power	**Thrust (N)**	**Torque (N.m)**
37,33	0,09156	0,027468
40	0,45453	0,136359
42,67	0,81096	0,243288
45,33	1,48131	0,444393
48	1,84428	0,553284
50,67	2,31189	0,693567
53,33	2,75334	0,826002
56	3,12285	0,936855
58,67	3,48255	1,044765
60	3,64605	1,093815

Table 3. Test Results - Propeller 10x4.5 ".

Propeller 10x4.5”		
% Motor power	**Thrust (N)**	**Torque (N.m)**
37,33	0,08175	0,024525
40	0,4671	0,140283
42,67	0,98427	0,295281
45,33	1,6023	0,48069
48	2,1582	0,64746
50,67	2,9103	0,87309

53,33	3,54141	1,062423
56	4,26081	1,278243
58,67	5,11755	1,535265
60	5,46417	1,639251

Figure 5 shows the comparison of generated torques, as found in Tables 2 and 3.

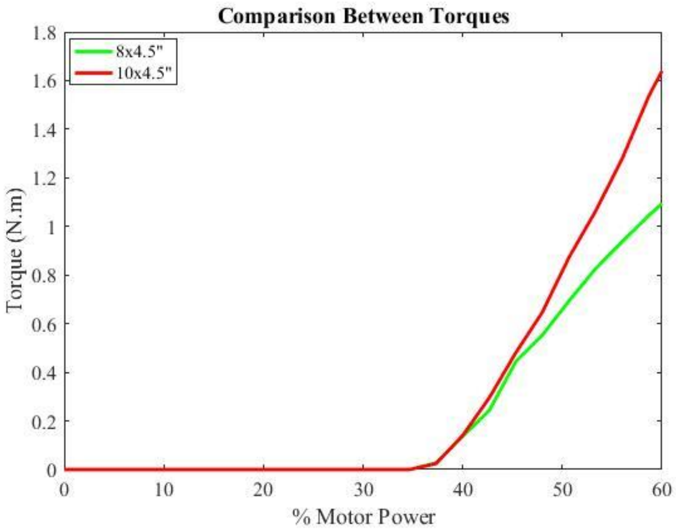

Figure 5. Comparison of Torque generated by Propellers

In figure 6 it is observed the comparison between the rotations measured for the propellers.

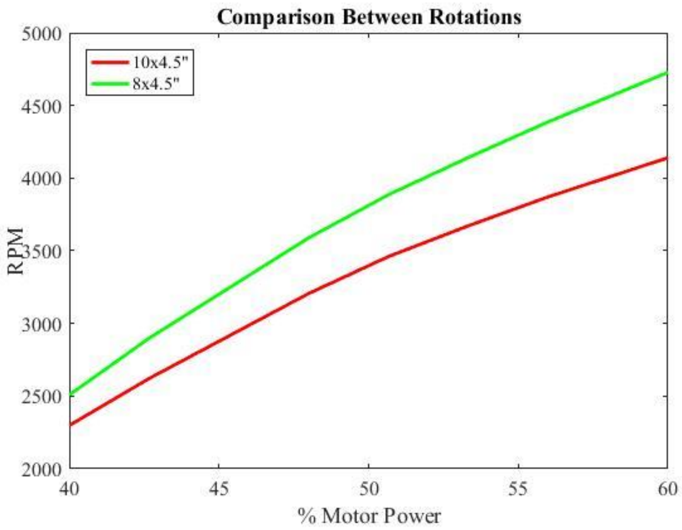

Figure 6. Comparison between propeller rotations

Analyzing Figure 6 and Tables 2 and 3, it turns out that the 8x4.5" propeller needs to achieve higher rotations in order to generate the same torque and thrust as the larger diameter propeller. In this way, the propellers 10x4.5 "are more suitable, because for a same power this propeller generates a greater thrust, guaranteeing greater stability to the quadricopter. However, the 8x4.5" propeller achieves higher RPM. In this way, thrust and torque parameters are directly proportional to the propeller diameter and inversely proportional to the rotation.

According to MathWorks (MathWorks, 2017), when exporting a CAD file to the Simscape Multibody, an XML multi-body description file is generated, containing the assembly structure and parameters that define each part of the assembly. For this to be done, one must install a plug-in, made available by MathWorks, to transform the assembly into an XML file.

In figure 7 we have torques results for both propellers using Simscape,

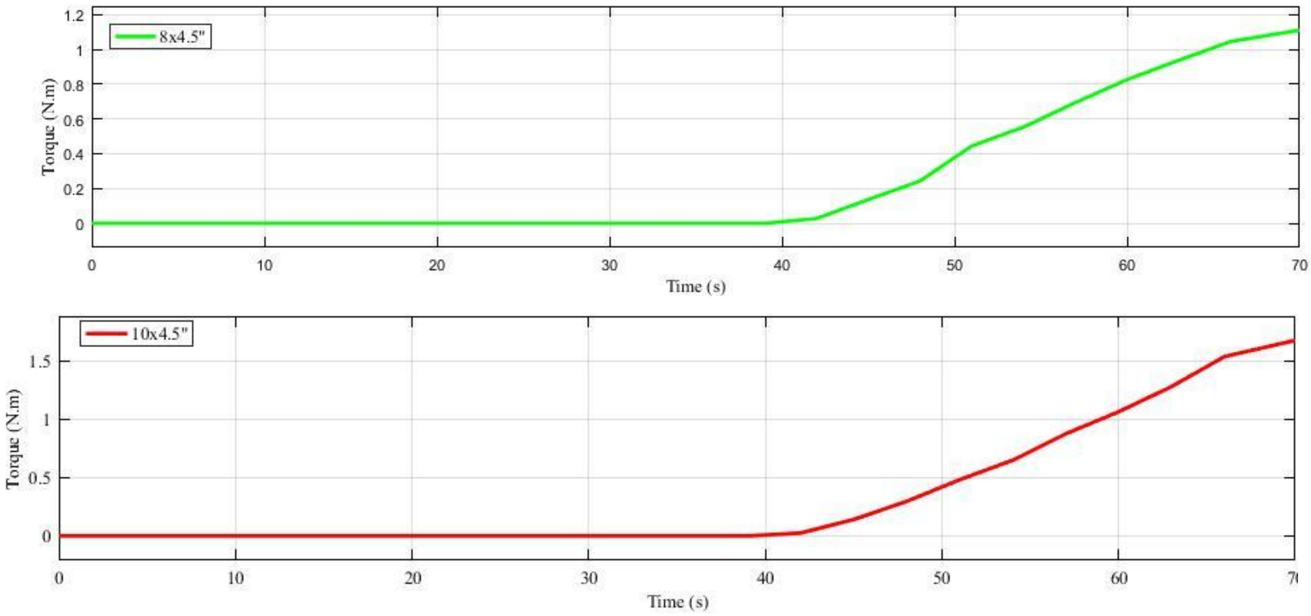

Figure 7. Torques estimated using Simscape

The behavior observed in the figure above is similar to those obtained experimentally, taking into account the restrictions, the material used and the vibration presented during the tests.

As we observed vibration during the tests, we were concerned to analyze their amplitude in order to evaluate their interference. To visualize the effect of propeller vibration on the structure, the maximum torque obtained in the tests performed for both propellers in SolidWorks was simulated. The simulations results can be observed in figures 8 and 9.

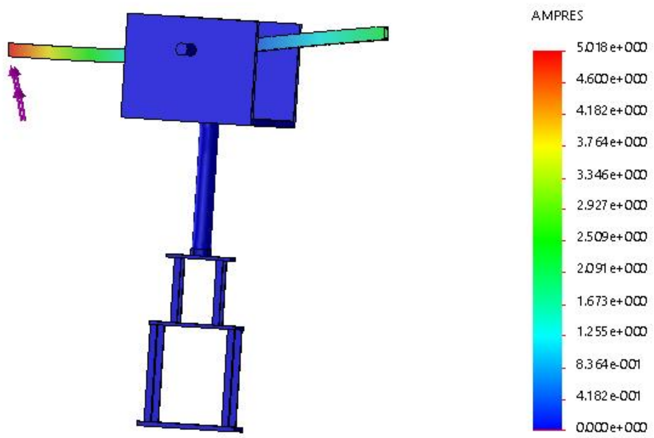

Figure 6. Comparison between propeller rotations

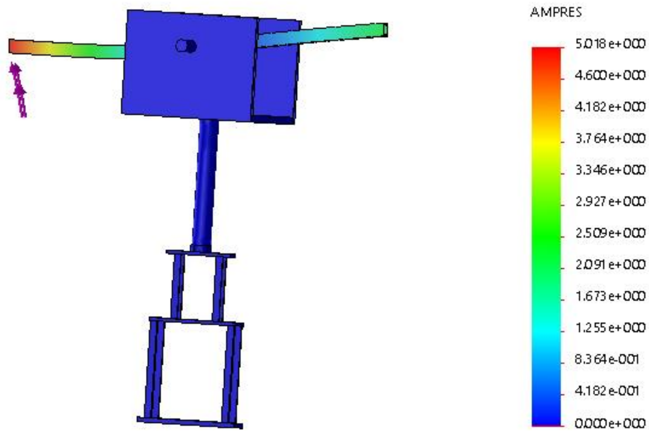

Figure 6. Comparison between propeller rotations

According to the simulation in SolidWorks, when inserting the maximum torque at one end, simulating what happens when the engine is turned on, for both propellers at their respective maximum torque values the vibration value in Hz would be approximately 174 Hz.

3. CONCLUSION

Despite being a relatively recent area of study, one can note the rising interest in scientific and technological development of unmanned aerial vehicles. The construction of this type of vehicle is not straightforward, since it involves several aspects such as hardware, software, use of sensors and the energy consumption management. The failure of one of these elements can lead to accidents, causing financial losses or even putting lives at risk (Maldonado,2014).

Although there is a wide range of applications, to obtain a satisfactory performance, it is necessary that the all parts in the project work harmonically. The proper choice of the propulsion system is one of the most relevant factors according to literature.

Our work presents comparisons between the results obtained experimentally and through simulation for a prototype test bench of a quadcopter motor-propeller pair, exhibiting similar values of torque for both approaches. Therefore, the test bench becomes a valid tool for the analysis of this parameter, within the specifications of the project. The next stages of development include the improvement of the 3D simulation and analysis of the behavior of the bench when more propellers are installed.

4. REFERENCES

Costa, S. E. A. P. “Controlo e Simulação de um Quadrirotor convencional”. 2008. Tese de Doutorado. MS thesis, Tech. Univ. of Lisbon. Lisbon.

Da Silva, Leonam Pecly; CORDEIRO, Cedric Salotto. Quadricóptero, aspectos gerais e análises da propulsão elétrica.

De Four, Ronald et al. “Operational Characteristics of Brushless DC Motors”.The University of the West Indies St. Augustine, Trinidad, 2007.

Export a SolidWorks Robot Assembly Model. Disponível em: < https://www.mathworks.com/help/physmod/smlink/ug/export-robot-assembly-from-solidworks-software.html>.

Güçlü, Anil. “Attitude and altitude control of an outdoor quadrotor”. 2012. Tese de Doutorado. ATILIM UNIVERSITY. ABCM, 2004.

Guimarães, Marco Paulo. Controle semiativo de vibrações por força de controle não linear. 2014.

Maldonado, J. C; barreto, R. S. Veículos Autônomos Não Tripulados: Perspectivas e Desafios. Revista da Sociedade Brasileira de Computação. Porto Alegre, n. 24, jan/2014.

Naidoo, Yogianandh; STOPFORTH, Riaan; BRIGHT, Glen. “Quad-rotor unmanned aerial vehicle helicopter modelling & control”. International Journal of Advanced Robotic Systems, v. 8, n. 4, p. 139-149, 2011.

5. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.